research review

OFFICE of AEROSPACE RESEARCH

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Magneto-Optical Double Resonance in Crystal Point Defects

DR. JAMES C. KEMP, Physics Department, University of Oregon

The best "microscope" we have for examining point defects in crystals, i.e., impurity ions, color centers, and the like, has been furnished by electron spin resonance (ESR), many point defects being paramagnetic. In the case of irradiation-induced defects, in fact, perhaps the only unambiguous assignments of structure have come from ESR, which reveals such details as the ground-state electron spin, the local symmetry and, when hyperfine splittings are present, the spatial relationship of a center to adjacent ions. Optical absorption bands of defects, on the other hand, are often not easily identifiable, for the reason that such bands are usually strongly broadened by electron-phonon interaction, to an extent that fine structure and other splittings, reflecting the electronic and geometrical structure of the center, tend to be unresolved. In materials with irradiation-induced centers, particularly, it is often impossible to prepare samples with only a single species of defect, and a complex optical spectrum must be dealt with. Since knowledge of the optical transitions is critical for understanding parameters of the material, such as the binding energies of electrons and holes trapped at defects, it is important to find ways to sort out the absorption spectra.

To solve this problem it is appealing to consider magneto-optical double-resonance techniques, with which one might demonstrate the relationship of the ESR spectrum of a paramagnetic species to an optical absorption peak (or peaks), in an immediate and direct way. My co-workers and I have recently applied such a technique at the University of Oregon, in work supported by a grant from the Solid State Sciences Division, Directorate of Physical Sciences, AFOSR. Our method utilizes Faraday rotation (rotation of the plane of polarization of light passing through a crystal along a magnetic field), and specifically the fact that Faraday rotation associated with a paramagnetic center may have a temperature-dependent or paramagnetic component, proportional to the differences between the populations of ground-state spin sublevels. In this circumstance, the paramagnetic rotation associated with the center can be artificially reduced, or even turned off, by simply saturating the spin resonance with microwave power. More

dramatically, by inverting the spin system, e.g., by adiabatic rapid passage, the rotation can sometimes be changed in sign.

It is understood that the spectral Faraday rotation $\theta(\omega)$ in any crystal is peaked up, in resonance fashion, around the absorption peaks. Exciting the spin resonance of one paramagnetic species should then selectively induce a change in the rotation pattern related to the absorption band (or possibly bands) of that species alone. This double-resonance principle is illustrated in Fig. 1, in which it is supposed that saturation of ESR line "a" is found to affect the rotation pattern related only to the band labelled "A".

The double resonance not only reveals the identification a $\longleftrightarrow$ A, but a plot $-\Delta\theta(\omega)$ of the microwave-sensitive signal also serves to isolate the rotation pattern shape related only to band A from the total rotation $\theta(\omega)$. As suggested in Fig. 1, the rotation patterns of absorption peaks are superimposed on a normally monotonic background, in practice consisting of the fundamental inter-band rotation in the crystal, plus possible spurious contributions originating in the apparatus. More important, rotation patterns due to absorption bands of other species of point defects, which may overlap with A, are eliminated. (It must be assumed or ascertained that saturation of "a" does not cause saturation of such other lines by so-called cross-relaxation.) To make quantitative use of the rotation pattern, obtained either from double resonance or directly from $\theta(\omega)$, one would need a specific model for the center involved, the magnitude and shape of the pattern relative to the absorption-band strength and shape depending in fact on details of the structure.

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JACOB SEIDEN
Editor

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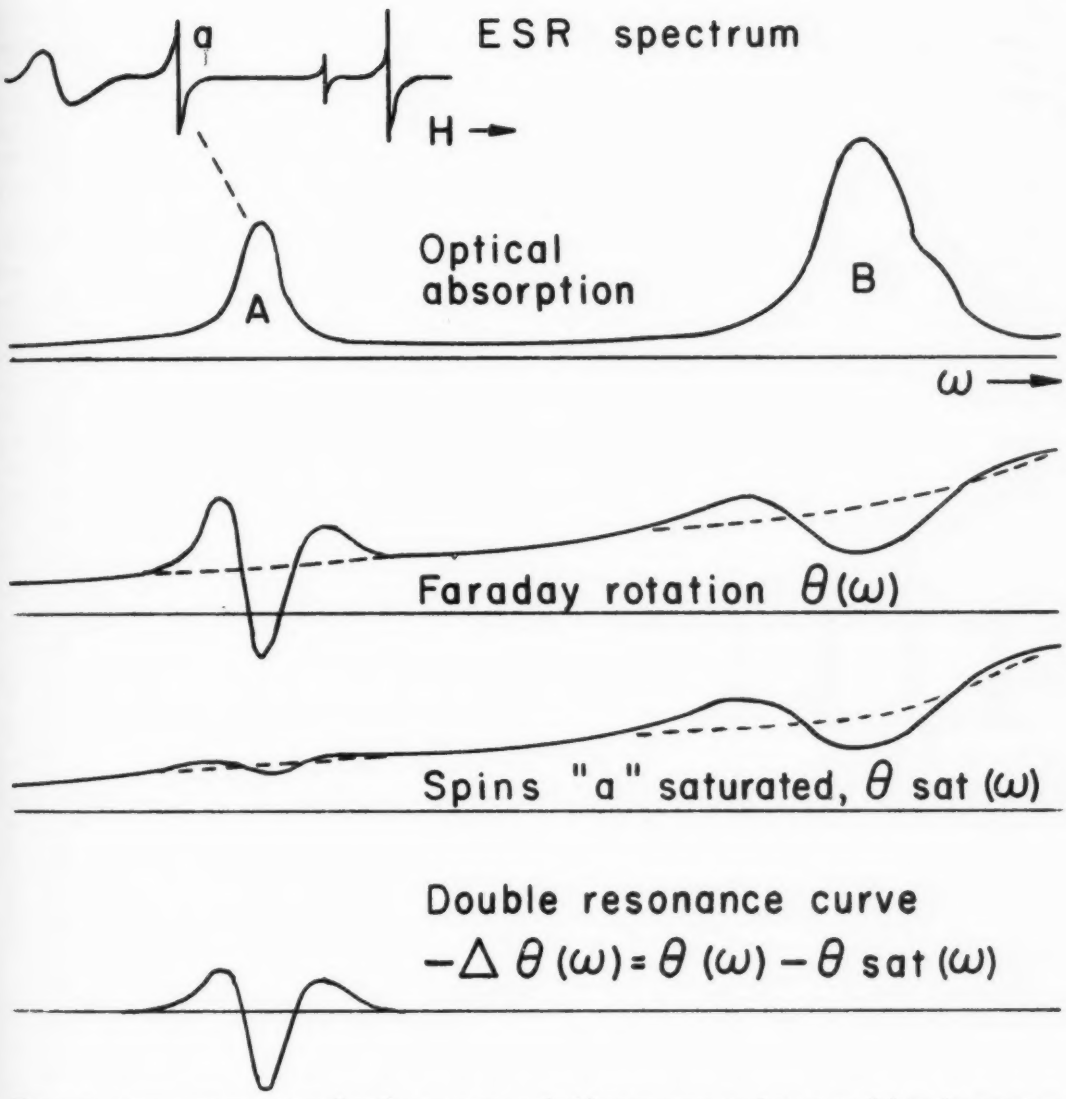

Figure 1. Microwave-sensitive Faraday rotation, a double-resonance technique useful in the spectroscopy of point defects in solids. A hypothetical situation is represented in which several species of defect centers, some of them paramagnetic, are present in a crystal, with various ESR lines and optical absorption bands. The ESR spectrum is the standard H-derivative, constant-frequency type. The double-resonance effect demonstrates that peaks "a" and "A" arise from the same species.

An application of this method to color center bands in the crystal CaO is depicted in Fig. 2, from data in reference 2. ESR spectra of the simple F center (one electron trapped in an oxygen vacancy) in the oxides MgO, CaO, and SrO have been known for several years; but the locations of corresponding F bands have been much in doubt, owing to the variety of other defects usually also present. (F centers in these crystals are normally produced by fast neutron irradiation.) As shown in the figure, a tempera-

ture-dependent pattern is seen in the Faraday rotation curves $\theta(\omega)$, apparently associated with the strong absorption band around 3.7 ev. Excitation of the F-center microwave spin resonance with 32 GC radiation, resonance field about 11.5 kilogauss, produced a double-resonance curve which establishes the approximate center of the F band, essentially coincident with the strong absorption peak. Quantitative estimates of the rotation amplitude in the CaO case, based on a simple theory, were found to be consistent with the measured data, if the F-center density from ESR measurement was used, and if theoretically reasonable values were chosen for certain parameters. The double-resonance curve in Fig. 2 was actually constructed in point-wise fashion by the technique of inverting the F-center ESR line by an adiabatic rapid-passage sequence, an abrupt change in θ, and subsequent transient decay to the thermal equilibrium value, being recorded at each of many fixed optical wave lengths. (Spin lattice relaxation times were of the order of seconds in the helium temperature region.)

It is clear that magneto-optical double-resonance methods of this and other types can be very useful in solid-state spectroscopy. A variant of the above method is to substitute magnetic circular dichroism for Faraday rotation. In either case the effect utilized depends on paramagnetism and is, of course, not usable in investigating diamagnetic point defects. Various other double-resonance schemes have also been proposed,

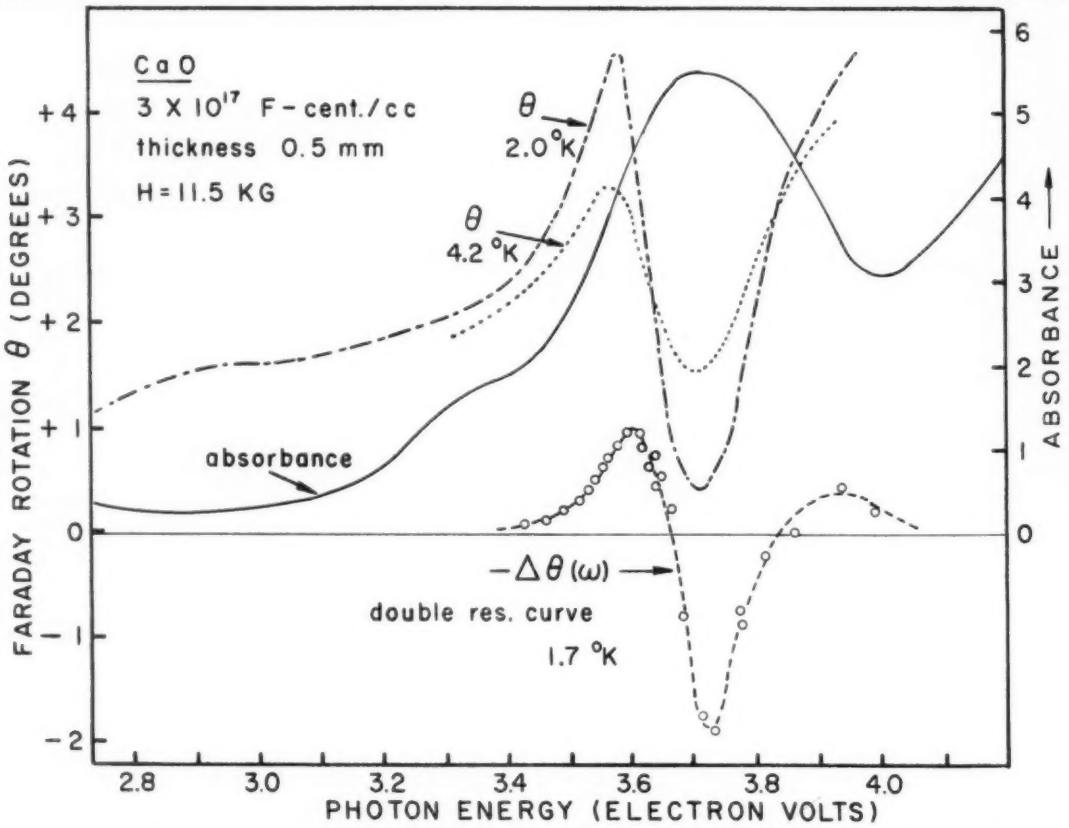

Figure 2. Double resonance, Faraday rotation, and absorbance curves in neutron-irradiated CaO, in the near ultraviolet. Experimental procedures used to take these data are described in reference 2. A strong absorption band at about 3,400 Å (3.7 ev) is shown by double resonance to be associated with the ESR line at g = 2.0001, assigned to the simple F center.

involving, for example, nonlinear mixing of microwave and laser radiation in excited states.

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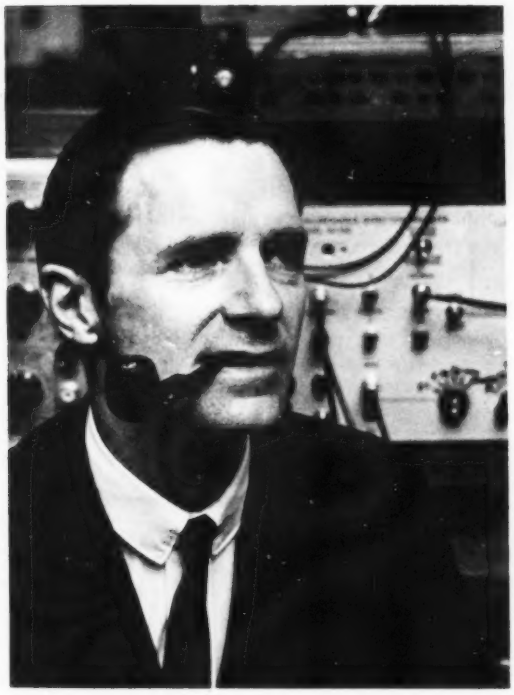

Dr. James C. Kemp, Associate Professor of Physics at the University of Oregon, Eugene, Oregon, is currently experimenting with insulator crystals. His main concern has been fundamental lattice defects, resulting, for example, from neutron damage, in the basic oxide ceramics MgO, CaO, and SrO. A contribution of his group has been a general understanding of the optical properties of the oxygen-vacancy F center.

Dr. Kemp received his A.B.(1955) and Ph.D. (1960) from the University of California, Berkeley. He served as radar technician in the U.S. Navy (1945-46) and in the Army Transport Service (1947-48). In 1960-61, he was a junior research physicist at the University of California, investigating spin echo phenomena under Professor E. L. Hahn. He has been with the University of Oregon since 1961.

AN EQUATION FOR CHARACTERISTIC CURVES

THOMAS K. KRUEGER

General Physics Research Laboratory, ARL

The problem of data reduction, common to scientific investigation in many areas, occurs in doing observational astronomy on gaseous nebulae with photographic emulsions. In this type of astronomy, which is part of the research effort at the General Physics Research Laboratory, photographic films or plates are exposed in a special camera placed at the focus of a large telescope of the kind found at Mount Wilson and at Mount Lick Observatories. When the emulsions are developed, the nebular spectrum is revealed as a series of lines of varying degrees of darkening. The wave lengths of the light causing some of the lines are known; what is desired is to find the wave length and intensity of the light causing the unknown lines by using the known lines as a reference. This knowledge aids in the determination of the physical conditions existing in the nebula and its chemical composition.

To analyze the lines on the emulsion, it is necessary to get a number of characteristic curves, each for a particular wave length of light. These are the familiar S-shaped curves giving the relationship between the transmission of light through the developed emulsion and the logarithm of the exposure of the light which made the image. Points for the curves are obtained using calibrated intensity steps or wedges, and these points are joined with a smooth curve. Values are then read off these curves to do the analysis. It is the plotting and reading of these curves which have prevented the analysis from being completely computerized.

An investigation was made to see whether these characteristic curves can be explained by a simple equation which would allow the elimination of the manual procedures in the data analysis. This equation would also pro-

vide a consistent means for extrapolating the curves beyond the experimental points where this is necessary; and it would also provide a means for "smoothing out" any errors which may exist in the experimental data.

About 1925 Baker (1) found that, for the photographic emulsions available then, the characteristic curve could be represented fairly accurately by an equation of the following form,

$$y = B\left[\ell n\left(\frac{1-a}{a}\right)\right] + C, \qquad (1)$$

where

a = transmission of the emulsion
y = $\log_{10}$ I
I = Exposure = Intensity x Time.

Since this equation can be analyzed quite easily by the method of least squares, it was investigated to see how well it would fit the characteristic curves for present emulsions. It is sometimes necessary in least-squares analysis to use a weighting function which allows for some points being more important, or more accurately measured, than others. Because of the greater difficulty in making transmission measurements for low and high exposures, the square of the deviation of each point from the curve is weighted by a factor w(a), with

$$w(a) = a(1-a). \qquad (2)$$

Several series of characteristic curves in the range of wave lengths from 3,500 to 5,000 angstroms have been analyzed using equations (1) and (2) on data taken from II a-O baked emulsions. It has been found that equation (1) satisfactorily describes the characteristic curves for this emulsion in the wave-length region specified. Fig. 1,

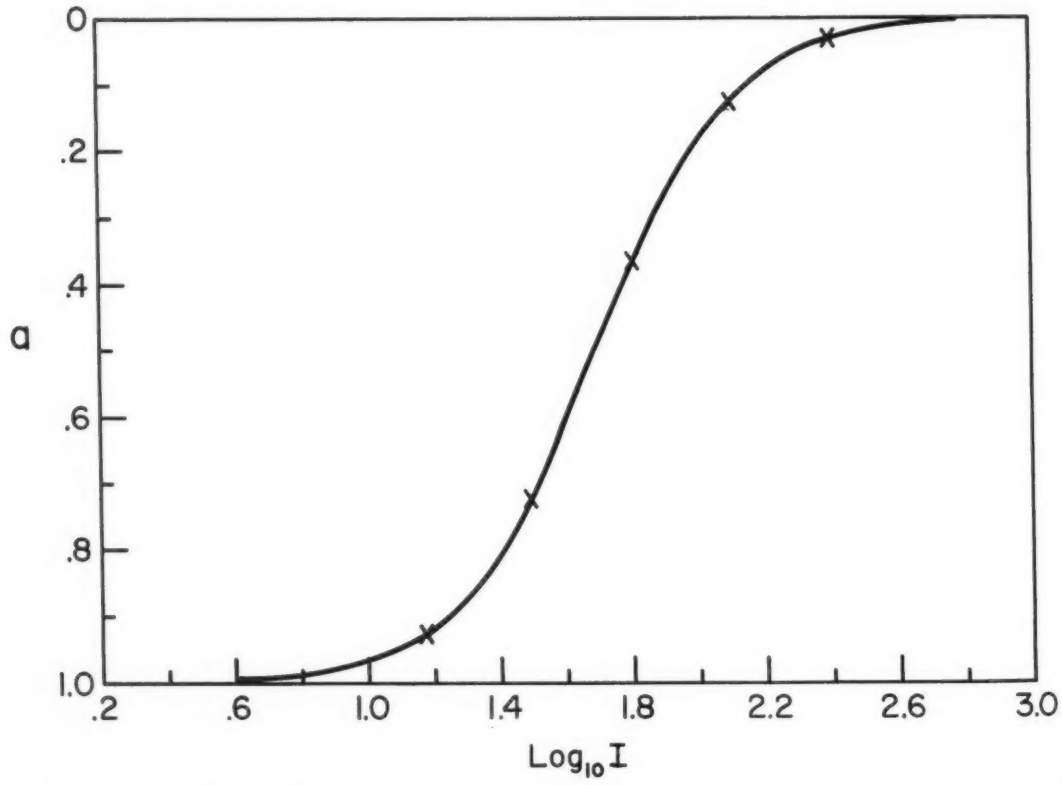

Figure 1. Sample characteristic curve at 4,000 angstroms.

for light at 4,000 angstroms, shows how one of these curves matches the experimental data which covers transmissions from about 3% to 93%. Equation (1) differs from Hurter's equation which gives the intensity as a function of density, the density being the negative of the logarithm of the transmission; the two equations are not simply related.

It has been found that using equation (1) saves about 25% of the computer time required to analyze the data by means of standard interpolation subroutines operating on tables made from the curves. It also saves a much larger percentage of the time which would be used in drawing the curves and making the tables from them.

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Mr. Thomas K. Krueger, a research physicist with the General Physics Research Laboratory, has been with ARL since 1955. He first worked with the 2-Mev Van de Graaff accelerator group, designing radiation shielding around the accelerator target and helping to develop a scintillation detection system that would record gamma rays with a high degree of resolution. Following that, he monitored contracts for the design of shielding around the reactors to be used for nuclear aircraft propulsion. In 1961, he started research on the theoretical transition probabilities and collision cross sections due to electron excitation for allowed and forbidden lines of atoms and ions of astrophysical interest. The results of these investigations are to be used to determine the abundances of elements in stars and nebulae, and to determine the electron density and temperature in these objects. Mr. Krueger has a B.S. in Physics, summa cum laude, (1953) from the College of St. Thomas, St. Paul, Minnesota, and an M.S. in Nuclear Engineering (1958) from the Air Force Institute of Technology. He has a number of publications to his credit.

electrostatic charging of fluid streams

EVERETT D. STEPHENS, Thermomechanics Research Laboratory, ARL

Sometimes our views as to "what is taking place" may be subject to some change when we take a "close look" at the detailed processes involved. Such has been the case with an ARL-TRW Systems jointly sponsored program to study the electrification of microscopic fluid streams under the direction of Dr. D. B. Langmuir and Dr. R. F. Wuerker of TRW Systems.

The studies showed that electrified glycerin emerging from small (typically 250 microns i.d.) needles held (in vacuum) at high electrical potential was in the form of micron-diameter filaments. It had been thought that the emission of glycerin from the needle would result in an abrupt transition into droplets. The demonstration made possible with the use of pulsed submicrosecond shadow and holographic observations indicated that the emission of the electrified glycerin in the range of charge-to-mass ratio of 0.1 - 20 coulombs per kilogram was primarily in the form of unstable micron-diameter electrified filaments of extremely high length-to-diameter ratio. Long charged filaments of glycerin were pulled from the liquid boundary and, as a result of the high charge-to-mass ratio per unit length, the filaments exhibited electrohydrodynamic instabilities primarily of the "kink" and "sausage" type. In addition, a

"length extension" instability was found whenever the stream was accelerated in a non-uniform electric field.

The "kink" instability was the dominant of the two instabilities, while the "sausage" instability was the one which led to the eventual breakup of the charged filament into droplets, usually after many thousands of filament diameters. As a result, the charge-to-mass ratio of the stream is determined while it is still intact and not by the droplet-formation process. Hence, the results of these studies indicate conditions contrary to those leading to the view that the charge-to-mass ratio and emission are in accordance with the simple Rayleigh theory of the charged liquid drop.

The liquid streams were pulsed at a rate which was a function of the mass flow rate, fluid conductivity, viscosity and electric-field intensity at the tip of the metal capillary. The number of jets in existence at any instant was a function of the applied electric-field intensity. The phenomenon was regular enough so that, when once established, the events repeated themselves in a consistent manner.

The new information on the formation process should provide a basis for a more realistic theory of liquid-stream electrification so as to permit the prediction of such important properties as charge-to-mass ratio, flow rates, and so forth, on the basis of controllable input properties like viscosity, conductivity, surface tension and applied voltage.

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Mr. Everett D. Stephens, an aerospace research engineer with the Thermomechanics Research Laboratory, ARL, received his B.S. in Mechanical Engineering cum laude from Howard University in 1938, and his M.S. in Mechanical Engineering from the University of Minnesota in 1941. He has also taken extension courses with the Ohio State University, and short courses with the University of California and the Massachusetts Institute of Technology. Mr. Stephens is currently conducting research in the areas of theoretical and experimental energy-conversion and transformation processes related to space-power generation and propulsion. He is also doing work on two-phase and two-component flows, and on techniques in charged colloid (particle) generation. Previously, he had worked as an aeronautical power-plant research engineer. Mr. Stephens has several publications to his credit.

Outline for Future Semiconductor-Materials Research

SOLID STATE SCIENCES LABORATORY
AFCRL

In a paper delivered recently before a meeting of the NASA Research Advisory Committee on Materials, Charles Ryan of AFCRL reviewed the present status of research and development in electronic materials and devices, and suggested new directions for future research.

Although we are presently witnessing an increasing stream of new ideas, materials, techniques and applications (integrated circuits, for example, after many years of R&D, have now arrived to mark a distinctly

new electronics epoch), we can discern a point on the horizon where the pace may slow down. It is Ryan's belief that so many researchers are so busily engaged in narrow and isolated aspects of semiconductor R&D, that a broader perspective of the field of semiconductor materials is being lost.

A disproportionate amount of semiconductor-materials research is too closely associated with specific, existing devices. Not enough emphasis is being given to a range of problems common to many classes of devices and to phenomena which would lead to the understanding necessary to predict and invent basically new types. Materials research, which was once too independent of device research, is now becoming enslaved to it.

In his talk, Mr. Ryan reviewed a number of approaches that might serve to redress the imbalance, and identified areas needing substantially increased support. He suggested that researchers should:

1) Investigate correlations among chemical-bond phenomena at one deeper level of comprehension;

2) Support basic theoretical efforts such as band theory;

3) In III-V compounds, emphasize wider-gap materials, particularly gallium phosphide and aluminum phosphide;

4) In group IV, emphasize beta silicon carbide;

5) In group II-VI, clarify the lattice-defect compensation problem and attempt to eliminate, control or circumvent it;

6) Determine the necessary and sufficient conditions for epitaxy and heterotaxy of compound semiconductors;

7) Extend our capacity for growing high-quality semiconducting and insulating crystals from 1,500° to 2,500° C;

8) Investigate new methods of more rapidly, accurately, and economically evaluating the chemical and structural perfection of semiconducting crystals, particularly wide-band-gap materials. ✪

a new light source for flash photolysis

DR. WILLIAM L. RUIGH
Directorate of Chemical Sciences, AFOSR

Flash photolysis is a relatively new technique introduced by Norrish and Porter in the late forties. It has been widely used to study photolysis reactions leading to transient products such as free radicals and excited species.

Professor Gilbert J. Mains of the University of Detroit, under AFOSR sponsorship, is studying a new type of flash source for photolysis called the theta-pinch plasma lamp. This new flash lamp is an adaptation of the plasma-pinch devices used in seeking controlled thermonuclear reactions. A schematic diagram of the lamp is shown in Fig. 1.

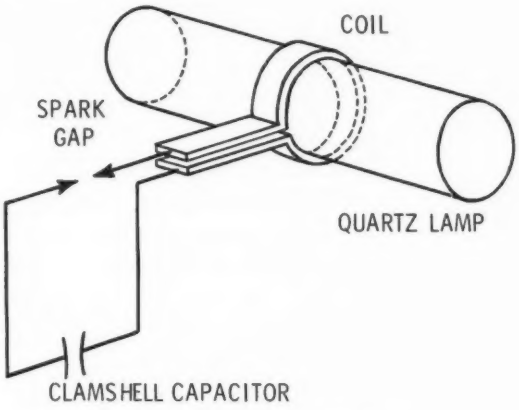


Figure 1. Theta Pinch Schematic.

The plasma is produced by discharging a "clamshell" capacitor via a spark gap through a coil surrounding a gas-filled lamp. The radiant power of the lamp is estimated at about a megawatt for a five-microsecond flash. The flash duration is measured in microseconds as compared to the millisecond flash of conventional electrode-type lamps. This rapid flash is a distinct advantage when studying unstable and transient species. The gas pressure for filling the lamp was found to be very critical, with an optimum

at about 10 torr for argon-xenon mixtures.

Light fluxes of the order of 10^{22} photons/cm^2 sec have been obtained, and this high flux leads to the possibility of biphotonic reactions being detected. A biphotonic reaction is one in which a second quantum of light reacts with a molecule already in the excited state. So far this has not been observed, although attempts are being made using a concentrated solution of naphthalene in ethanol.

By putting a LiF window in the lamp, it has been used in the vacuum ultraviolet region for such reactions as CO_2 giving CO. The measurement of the flux was done by both physical and chemical means. In the latter case, the ferrioxalate actinometer was used. The reaction here is the light-initiated conversion of Fe^{+3} to Fe^{+2}. The amount of Fe is estimated spectrophotometrically using an Fe^{+2} complex with phenanthroline to develop the color.

The investigation of the theta-pinch plasma lamp has proceeded in several stages: development of techniques for measuring flash lifetimes and intensities; application of these techniques in determining the effect of varying electrical and physical properties of the circuitry and of the lamps on the flash intensity and the flash lifetimes; and finally, utilization of the theta-pinch plasma as a flash source for chemical studies.

The use of the theta-pinch plasma flash lamp is still in the preliminary stages; but sufficient results have been obtained to demonstrate that this flash lamp will be a useful tool for photochemistry. First, the apparatus is relatively inexpensive and compact, compared to conventional flash lamps. Second, the improved decay time, without loss of light flux, will enable shorter-lifetime transient species to be observed. And, perhaps most important of all, this flash lamp has proven to be extremely versatile in its range of applications. It is possible that, with suitable development, the theta-pinch lamp could offer advantages in applications such as aircraft runway lights and beacons.

ANNIVERSARY OF OV3-1

CHARLES H. REYNOLDS
Aerospace Instrumentation Laboratory, AFCRL

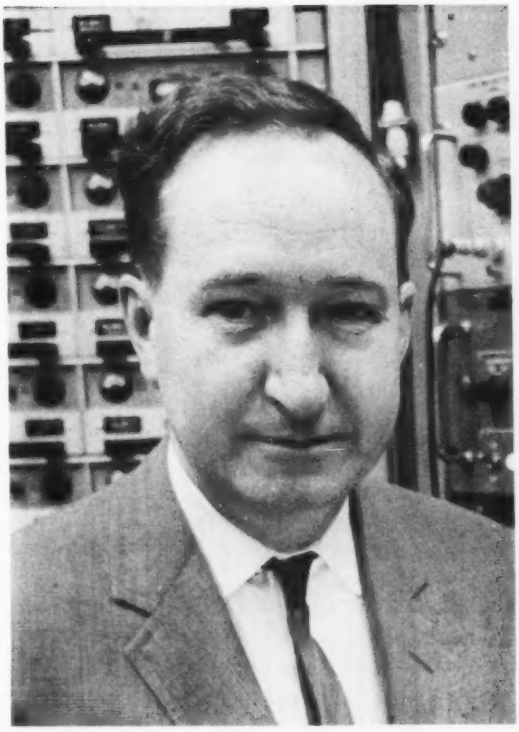
The month of April 1967 marked the anniversary of the orbiting of the OV3-1. This was the first in a series of 6 OAR satellites to be launched on the Scout under the technical management of the Air Force Cambridge Research Laboratories. Five satellites were launched in a period of less than 10 months. The first 4 were successful, but the fifth failed to achieve orbit due to a malfunction of the fourth-stage rocket motor.

The OV3-1 carries experiments to make measurements in the earth's radiation belt. Although the spacecraft was designed for a life of 6 months, all satellite systems are still in excellent operating condition, and meaningful scientific data are still being collected after the completion of over 3,000 orbits and the lapse of 1 year. The experiments are now routinely activated only once a week in order to determine their status, since sufficient data under normal conditions have already been obtained. However, during periods of high solar activity, data are taken at the highest rate consistent with range-scheduling capability.

Two of the other three OV3 satellites (OV3-4 and OV3-3) are also maintained on the same "station-keeping" basis except during periods of high solar activity since the experimenters (the Air Force Weapons Laboratory and the Space Systems Division/Aerospace) have obtained sufficient routine data and wish to prolong the spacecraft's lifetime to the maximum possible time. The fourth satellite, OV3-2, is still operational, although not in the tape-recorder mode. Valuable data in the polar regions are being collected by an operational procedure whereby the satellite is turned on by one of the usual control stations and allowed to remain on until the next pass over the same or another appropriate command sta-

tion. This technique is necessary since the polar stations, although capable of recording satellite telemetry, do not have command capability compatible with the spacecraft.

The final satellite in the series, OV3-6, is scheduled for launch during the fourth quarter of this year. ✪



Mr. Charles H. Reynolds, Chief of the Research Probe Instrumentation Branch, Aerospace Instrumentation Laboratory, AFCRL, has been assigned by OAR as the technical manager for the OV3 program. With AFCRL since 1955, his current work includes telemetry, tracking and range safety systems for all AFCRL probes, solar orientation devices for rockets and satellites, and consideration of data-processing methods and techniques. Prior to coming to AFCRL, he was an electronic engineer with the U.S. Army Signal Corps Engineering Laboratories, and involved in operations research for the Army Electronic Proving Group at Ft. Huachuca, Arizona. Mr. Reynolds has a B.S. (1949) and an M.S. (1952), both in Electrical Engineering and both from Rutgers University. He is a member of Tau Beta Pi.

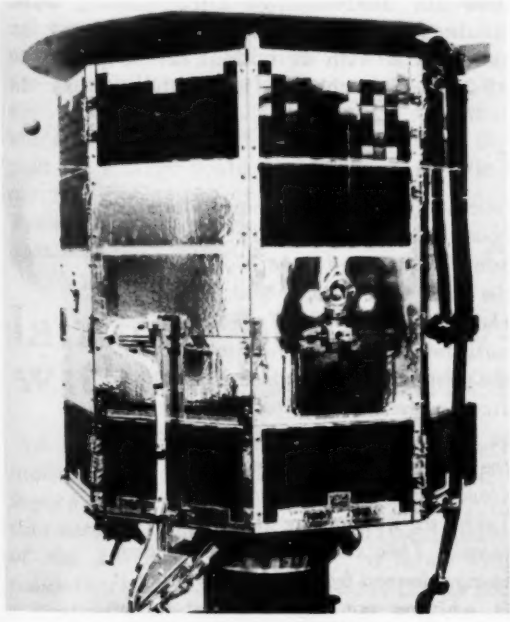


Figure 1. OV3-1 satellite.

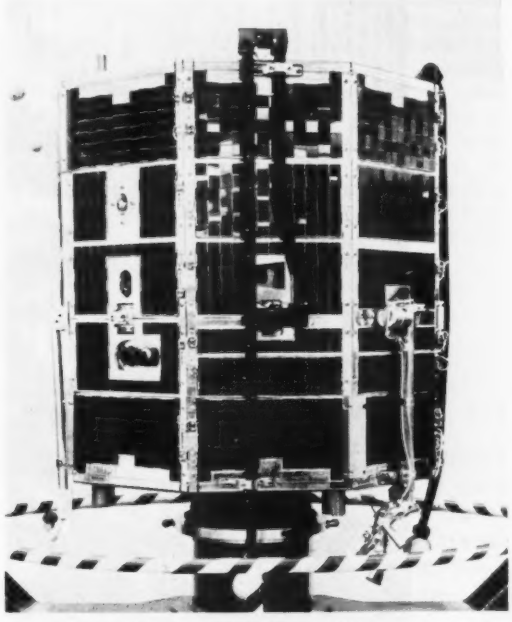


Figure 2. OV3-2 satellite.

lunar hot spot

SPACE PHYSICS LABORATORY, AFCRL

The major "hot spot" on the moon is not volcanic, according to Drs. John W. Salisbury and Graham R. Hunt of AFCRL. This conclusion was reached after extensive measurements made by the AFCRL scientists using a unique device which produces visible images of the infrared emissions of the lunar surface (Figure 1). Many scientists have speculated that the hot spot may be of volcanic origin.

With the extremely sensitive AFCRL imaging device, thermal photographs of the moon can be produced long after lunar sunset, during the dark of the moon. Although the lunar surface cools rapidly to several hundred degrees below zero when not illuminated by the sun, enough heat is given off to be detected with the device.

Thermal images of the major lunar hot spot, so called because it cools more slowly than its surroundings after sunset, were obtained by using the infrared imager in association with an optical telescope at the AFCRL Strawberry Hill Observatory in

Figure 1.

Infrared image of the lunar surface 22 hours after the crater Tycho (curved arrow) has ceased to be illuminated by the sun. Hot illuminated terrain is shown to the left of Tycho and thermally featureless dark terrain surrounds the crater. Darker shades of gray indicate warmer temperatures; and it can be seen that the steeper slopes facing the sun (to the left) are warmer than slopes facing away from the sun, for Tycho as well as for the illuminated terrain. This solar effect on the heat being released by Tycho shows that it is emitting not volcanic, but rather stored solar heat.

Concord, Mass. This hot spot, associated with the crater Tycho, has a pattern of heat distribution which is very similar to the pattern of solar illumination just before lunar sunset. Because of the clear relationship between heat release and solar illumination, the two AFCRL scientists concluded that the crater is emitting stored solar heat.

The moon has many areas on its surface which cool more slowly than their surroundings after lunar sunset or during an eclipse. The "warmest" areas are associated with craters, and particularly with craters that are surrounded by a white halo or white rays. These are relatively recent formations on the lunar surface, and it has been supposed by some scientists that the craters, or at least the additional heat that they possess, might be of volcanic origin. Others have claimed that the moon is a "dead" body, without sufficient internal heat to support volcanic activity.

The Tycho thermal anomaly is the largest crater hot spot on the moon, and so was particularly likely to show the evidence of any recent volcanism. Because the AFCRL infrared images reveal only stored solar heat, it appears that volcanism probably did not play a major role in the origin of the crater. Salisbury and Hunt do not rule out the possibility of volcanism elsewhere on the moon, however. They point out that volcanism has apparently been active in the past on a large scale in the formation of the maria, and that other hot spots besides Tycho may have resulted from internal heat.

Drs. Graham R. Hunt (left) and John W. Salisbury are with the Lunar-Planetary Research Branch, Space Physics Laboratory, AFCRL.

Dr. Hunt is a physical chemist whose current work involves the application of spectroscopic techniques to the study of probable lunar-surface materials, their dielectric constants, and the effects of radiation upon them. He has a B.Sc. (Hons) (1952), an M.Sc. (1954), and a Ph.D (1958), all in Physical Chemistry, and all from the University of Sydney, Australia.

Dr. Salisbury, Chief of the Lunar-Planetary Research Branch, directs a program of research on the nature of both lunar and planetary environments. His own investigations are concerned primarily with the origin of lunar-surface features and the composition and nature of lunar-surface materials. He has a B.A. in Geology magna cum laude (1955) from Amherst College, and an M.S. (1957) and Ph.D. (1959), both in Geology and both from Yale University.

laminar boundary-layer flow with mass transfer

CAPT HOWARD E. BETHEL
Hypersonic Research Laboratory, ARL

A detailed study of the GKD multimoment method for incompressible laminar boundary layers was presented in Reference 1. In this note, a summary is given of an extension of the aforementioned study to flows with mass transfer, axially symmetric flows, and a limited class of compressible flows (see Ref. 2).

The steady, axially symmetric laminar boundary-layer equations for a limited class of compressible flows which can be transformed by an Illingsworth-Stewartson transformation to a related incompressible form were considered. A system of N linearly independent integral conditions was derived by the same procedure employed in Refer-

ence 1. However, the resulting system of integral conditions has two additional terms. One of these terms accounts for the mass transfer, and the other the axially symmetric nature of the flow. The former term is identically zero for solid boundaries, and the latter for flow over two-dimensional bodies.

In the past, severe limitations have been found when approximate methods devised for solid boundaries have been used to calculate flows with mass transfer. Furthermore, some methods devised specifically for flows with suction have been applicable to only a limited range of suction velocities (Ref. 3). In this study, the same approximating functions employed for two-dimensional flows with zero mass transfer were used because of their very general form. If nothing more, the limitations of this straightforward formulation could be identified. The approximating functions utilized were $\theta_{A,\,N} \sim (1-\bar{u})^{-1}$ and, near separation, $\theta_{R,\,N} \sim (1-\bar{u})^{-1}\,[a\,(x)+\bar{u}\,]^{-1/2}$ where $\bar{u} = u/U_e$ and a is a determinable coefficient which approaches zero as $x \longrightarrow x_s$, the separation point.

The convergence and exactness properties of the approximate solutions of four similar flows were found. Three of these flows were two-dimensional and spanned the spectrum of flows with mass transfer. They were the stagnation-point flow, flat-plate flow, and separation-point flow. The axially symmetric stagnation-point flow was also evaluated. The results for stagnation-point flow are given in Fig. 1. For all values of the mass-transfer parameter, the convergence is uniform. The approximate solutions are less than one percent in error for the second and higher

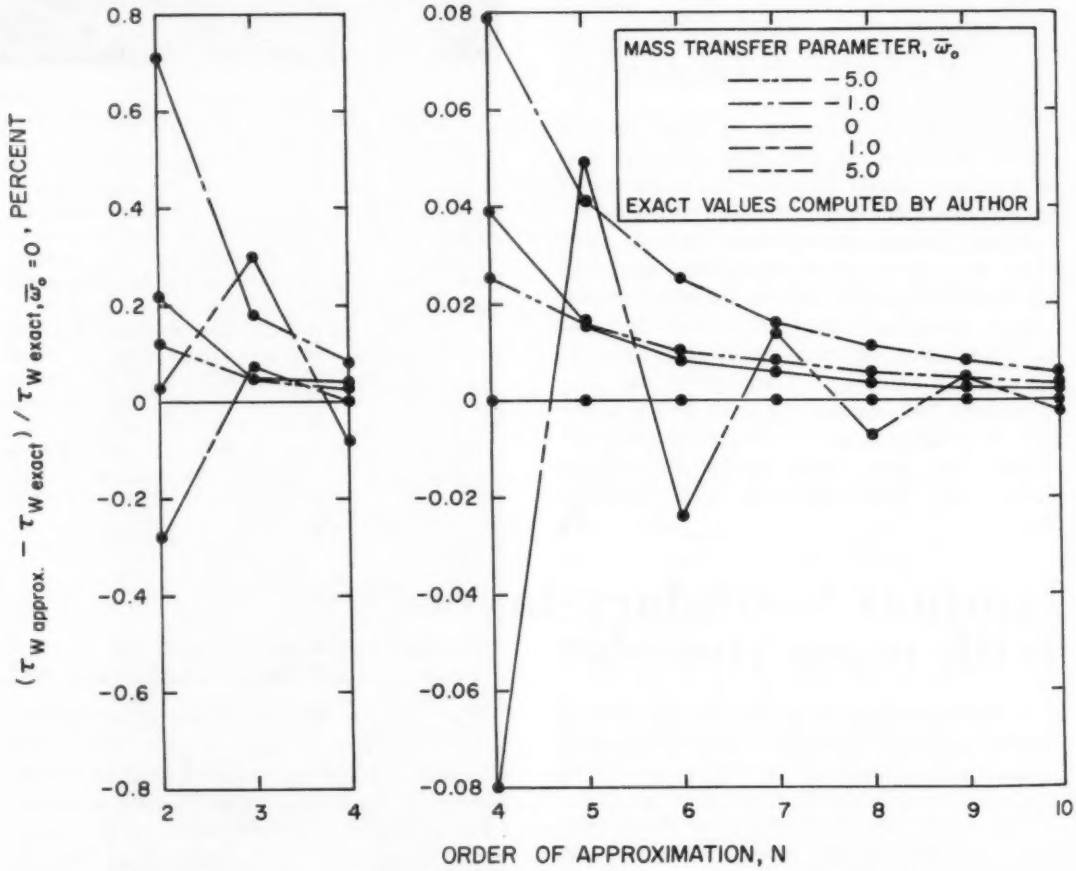


Figure 1. Convergence and exactness of stagnation-point flow with mass transfer.

orders of approximation. For the other flows, the convergence and exactness properties were generally similar to those given here. The least accurate approximate solutions were found for flat-plate flow with strong injection. On the basis of the above results, the fourth order of approximation was suggested as the best compromise between the requirements for accuracy and computational feasibility.

An effort was made to comprehensively test the application of the GKD method to flows with mass transfer. This was done by evaluating the approximate solutions (N = 4) of many of the flows for which "exact" numerical solutions are available. The trial calculations included the following flows:

a. similar flows with mass transfer,
b. flat-plate flow with continuous, discontinuous, and impulse suction,
c. circular cylinder with suction,
d. flat-plate flow with injection,
e. axially symmetric stagnation-point flow with mass transfer, and
f. flow over a sphere with suction.

The flow over a circular cylinder ($U_e = U_\infty \sin x$) with suction has been solved by a difference-differential method by Terrill (Ref. 4). The approximate solution for this flow was obtained by the present method and is compared with that of Terrill in Fig. 2.

Nickel has rigorously established that no finite amount of suction can cause the wall shear stress to become zero in an accelerated flow (Ref. 5). The wall shear stress can be reduced to zero by a finite amount of blowing for flat-plate flow and retarded flows. The required amount of blowing varies from zero for the separation-point flow to a maximum value for flat-plate flow. For a flat plate with uniform injection, the velocity profiles in the vicinity of blowoff have an extreme form (Ref. 6) which is not adequately reproduced by the present formulation of the GKD method.

In conclusion, the GKD multimoment method has been applied to a variety of two-dimensional and axially symmetric flows with mass transfer. The approximate solutions evidence convergence and, in general, an exactness of one percent for the third and higher orders of approximation. The only limitation was found in the neighborhood of blowoff for $\beta \longrightarrow 0$. In view of previous experience, it is somewhat remarkable that the approximating functions devised for two-dimensional flows with zero mass transfer handle axially symmetric flows and two-

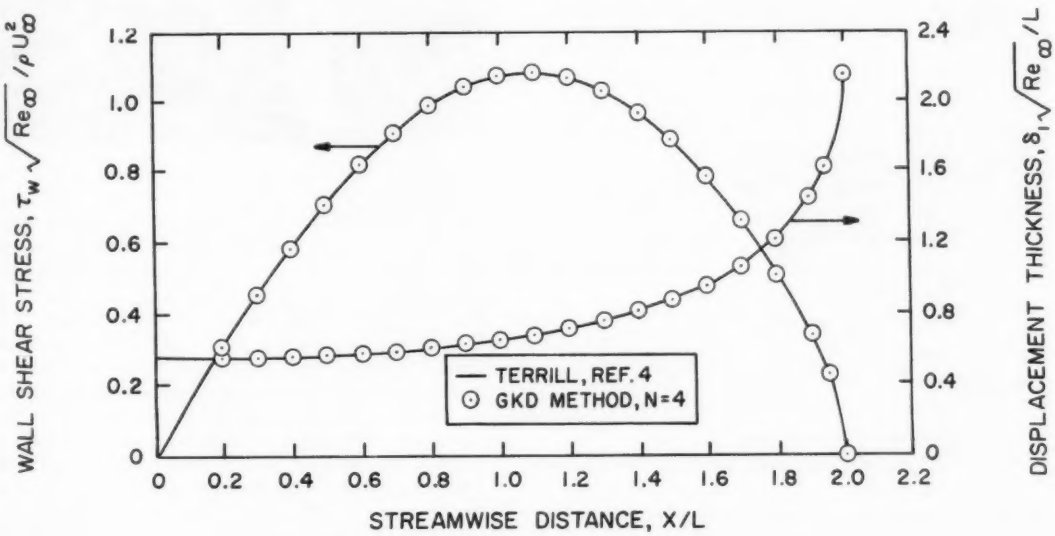


Figure 2. Flow over circular cylinder with suction.

dimensional flows with mass transfer with the same degree of accuracy.

The author is indebted to Captain K. O. W. Ball of ARL for making available a program for evaluating the exact similar flow solutions with mass transfer.

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NOMENCLATURE

$\bar{u}$	normalized velocity, u/U_e
x, y	streamwise and normal co-ordinates in physical plane
x_s	separation point
N	number of coefficients in approximating function
U_e	velocity in the free stream
U_∞	reference velocity
$\alpha(\xi)$	coefficient in approximating function $\theta_{R,N}$
β	similar flow parameter
ξ, η	transformed streamwise and normal co-ordinates
$\theta(\xi, \bar{u})$	dependent variable in transformed co-ordinate system, $[\partial \bar{u} / \partial \eta]^{-1}$
$\theta_{A,N}, \theta_{R,N}$	approximating functions for $\theta(\xi, \bar{u})$

Captain Howard E. Bethel is a research engineer with the Hypersonic Research Laboratory, ARL. He has recently completed a detailed study of the solution of the laminar boundary-layer equations with the Galerkin-Kantorovich-Dorodnitsyn method, and is continuing his research on computational methods in boundary-layer theory. Captain Bethel received a B.S. in Aeronautical Engineering, with distinction, from Purdue University in June 1961. He was commissioned in the Regular Air Force at the same time, and stationed at Purdue where he conducted research on solid-propellant combustion phenomena. Also, while at Purdue, he received an M.S. in Engineering in June 1963, and satisfied the Ph.D. residence requirements. After coming to ARL in 1964, he completed his dissertation in absentia, and was awarded the Ph.D. degree in June 1966. Captain Bethel has several publications to his credit.

microseismic noise-detection system

TERRESTRIAL SCIENCES LABORATORY, AFCRL

A highly sensitive seismic detection system for measuring small-scale earth vibrations has been developed by AFCRL scientists. The portable system was developed by Henry A. Ossing and Francis A. Crowley from commercially available components. The distinctive features of the system are its operational deployment plus a computer program for extracting maximum information from the seismic data. Using data from the multielement seismic array, the computer performs such functions as multiple-correlation, convolution, power spectral densities, and so on.

The system is designed to measure the relative intensities of environmental seismic noise at various locations. The earth's seismic noise field has many origins, with the most obvious being the slight shifts (sometimes occurring in response to lunar gravitational pull) in the earth's crustal materials. But earth vibrations are also induced by heavy surf in areas near the ocean, by trains, by rocket and missile launches and by aircraft operations.

Seismic noise affects the operation of such motion-sensitive equipments as multiple-phased antenna arrays and millimeter-wave

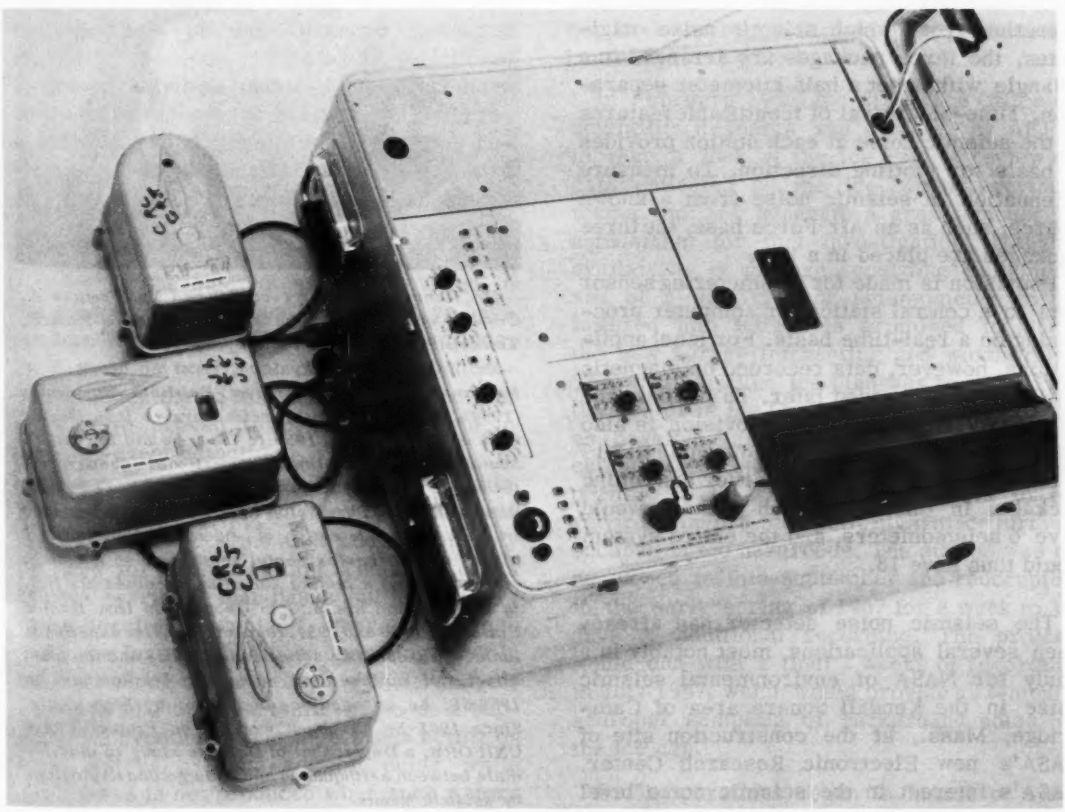

Figure 1. AFCRL's portable seismic detection apparatus for measuring small-scale earth vibrations.

antennas. Test and calibration of optical systems and of inertial devices for guidance control are strongly affected. Even in growing single crystals of materials, small vibrations can cause a misalignment of atoms in the crystal lattice structure.

The basic sensing elements of the AFCRL seismic array are EV-17 seismometers (built by Electro-Technical Labs) which, depending on type, detect either the horizontal or vertical components of vibration. These small, 13-pound, inertial-mass systems are buried 5 inches to a foot underground. Three of these seismometers (one to measure vertical and two to measure horizontal vibrations) provide inputs to a portable recording and timing package. IN AFCRL's present operations, 3 of these portable packages are used.

The three portable packages, each with its three seismometers, can be arranged in a variety of geometries, depending upon the particular investigation. To determine the direction from which seismic noise originates, the three packages are arranged in a triangle with about a half-kilometer separation. Time-of-arrival of identifiable features in the seismic noise at each station provides a basis for plotting direction. To measure attenuation of seismic noise from a known source, such as an Air Force base, the three packages are placed in a line.

Provision is made for telemetering sensor data to a central station for computer processing on a real-time basis. For most applications, however, data recorded on magnetic tape can be processed later. To improve the sensitivity of the system, provision is also made for the use of 3 additional EV-17 seismic sensors in each recorder and timing package. In this case, each package would have 6 seismometers, and the entire system would thus have 18.

The seismic noise detector has already seen several applications, most notably in a study for NASA of environmental seismic noise in the Kendall Square area of Cambridge, Mass., at the construction site of NASA's new Electronic Research Center. NASA's interest in the seismic noise level of the new laboratory arose from its planned research on inertial and optical systems.

AFCRL is presently using the system to measure the environmental seismic noise of air bases. One of the goals of the program is to possibly predict seismic noise in given locations. A magnetic-tape library of environmental seismic noise associated with air bases is now being compiled by AFCRL. The seismic system and its associated processing procedures have proved to be so effective that AFCRL scientists have found it feasible to identify various aircraft through their take-off and landing seismic signatures.

Mr. Henry A. Ossing (seated) and Mr. Francis A. Crowley are both with the Wave Propagation Branch, Terrestrial Sciences Laboratory, AFCRL.

Mr. Ossing, a geophysicist, received his B.S. in Mathematics cum laude from Fairfield University (1954), and his Master's in Geophysics from Boston College (1961). From 1959 to 1961, he did foundation soundings incorporating explorational geophysical techniques, under the supervision of Father Linehan, S.J., of Weston Observatory. He is currently engaged in work on the detection of underground nuclear explosions and in environmental seismic-noise research.

Mr. Crowley, a project scientist, received his B.S. in Physics and his M.S. in Geophysics from Boston College in 1950 and 1951, respectively. His experience includes research on seismic phenomena and the blast effects of surface and subsurface explosions. In 1958-60, he engaged in studies of the high arctic. Since 1961 he has been working on Project VELA UNIFORM, a Department of Defense study to discriminate between earthquakes and underground explosions by seismic means.

Both scientists have several publications to their credit.

survey of seismic noise on the Greenland Ice Cap

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Danish Geodetic Institute and
MAJ DURWARD D. YOUNG, JR.
Directorate of Physical Sciences, AFOSR

Seismologists the world over are eternally in quest of that magic set of conditions best described as a "quiet site." In real life such seismic laboratory locations free of background noise, far from cultural noise sources yet strategically located with respect to the world's major seismically active areas, simply do not exist. However, the search for the best possible site goes on. Prior to the present decade, seismologists usually had to be content with observatories located in close proximity to educational and governmental institutions for reasons of technological and financial support. This has changed rapidly in the last decade, during the International Geophysical Year and, early in 1961, with the inception of the Advanced Research Projects Agency's (ARPA's) Vela-Uniform project. Activities under this project have ranged from basic theoretical seismic research to instrumentation design and development. Under this charter the entire earth's surface was considered the laboratory for investigation for the best seismic recording locations.

Some of the quietest sites discovered in the course of numerous noise surveys have become sites of seismic array stations. Such stations utilize an array of seismometers rather than a single recording location. They have proved to be very efficient in seismic-event detection.

Danish authorities have been interested in the question as to whether or not their territory offers sites that could profitably be used for such a station. The only part of Danish territory that has a sufficiently low noise level is Greenland, where the Danish Geodetic Institute has been operating seismic stations along the coasts since 1928. Analysis of these and other seismic-noise data support the hypothesis that high winds acting on open waters produce seismic noise, while such noise is not produced when such waters are ice covered (1, 2). Thus, the high-arctic areas have an advantage for installation of seismic stations. A type of noise which disturbs a station's detection capability is noise of a one-second period. This noise is very much attenuated when it has propagated more than a few hundred kilometers; hence, the center of the ice cap could be expected to be relatively free of such noise. Noise due to the cracking of ice and the melting of water is also expected to be at a minimum in this environment. Therefore, the Danish authorities have asked ARPA to investigate the noise characteristics on the Greenland Ice Cap in co-operation with the Danish Geodetic Institute.

In February 1966, the Air Force Office of Scientific Research was directed by ARPA to take a look at the ice cap. A review of data collected on the ice cap by previous teams did not generate a great amount of enthusiasm for this investigation, but the availability of modern recording equipment and of a new type of seismometer to be lowered into boreholes promised to make the new survey interesting and worthwhile. The original Blue Ice plan was to move into the center of the Greenland Ice Cap as early as possible in the summer of 1966 and to establish the station in sufficient time to permit at least one month's data to be recorded before the arctic night made further occupation too hazardous. The station was to be closed in mid-September and reoccupied in the early spring of 1967 for a week to 10 days of additional recording. The project would end with a final 2 weeks of recording in July 1967, which would provide a 12-month seasonal sampling of background noise on the ice cap.

Field operations began in March of 1966 when the Arctic Institute of North America

in Washington, D.C., was awarded a contract to establish and operate a base field camp to support the seismic program. The exact location was not initially important, but was to be selected such that maximum distance from all sources of cultural and natural noises would be obtained. This part of the operation was under the able direction and leadership of Mr. Ralph Lenton, of the Arctic Institute of North America, who effectively put the camp together from the planning stage to full operation in less than 6 months. The site of the seismic station was arbitrarily dart-picked at latitude 78°N and longitude 40°W by the Arctic Institute of North America with the clairvoyance of one gifted in the art (science?) of rhabdomancy. Air logistic support from Thule, Greenland, to the interior of the ice cap was provided by Headquarters Alaskan Air Command from Elmendorf AFB, Alaska, using ski-equipped C-130 Hercules aircraft operated by the 17th Troop Carrier Squadron. The initial fly-in required that the lead aircraft depart Thule with adequate survival gear for the initial landing on an unprepared open area of the ice cap.

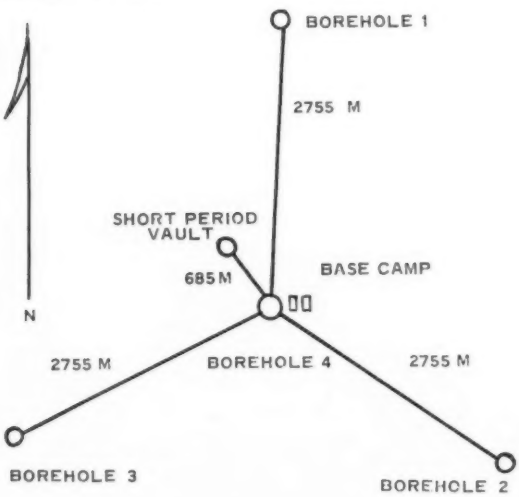

Figure 1. Location of seismometers at Station Inge Lehmann, Greenland.

The lead aircraft could not make visual surface contact at the dead-reckoned co-ordinates of 78°N - 40°W. A break came when the abandoned British 1952-54 Northice Station was sighted through the cloud cover. The site-selection aircraft then flew under the low cloud cover approximately 14 miles and, upon landing, established the Inge Lehmann Station at 77°57'N and 39°11'W. These co-ordinates were verified by a number of theodolite sun shots and have a probable error of about 1 km. This location error is considered within the acceptable limits for event detection studies.

The initial touchdown was accomplished on 19 June 1966. The camp nucleus then consisted of 1 skid-mounted trailer and 6 scientific personnel. This landing party was rapidly augmented to a full station complement of 10, and approximately 60 tons of camp and scientific gear. Approximately 8 missions (round trips) were required for the Hercules C-130's to establish the base camp. This was completed in 6 days without serious incident except for the loss of 1 engine when a propeller dug into a sastrugi ridge. The aircraft was airborne again within 72 hours with a replacement engine changed by USAF technicians on the ice cap.

The seismic array consisted of 4 downhole short-period seismometers located at the center and apices of an equiangular triangle as illustrated in Figure 1. A 3-component short-period surface station completed the instrumentation. The base camp consisted of two 20-foot-long skid-mounted trailers positioned to provide an 18-foot covered vestibule work space between them. One trailer served as a cooking, messing, and recreation facility. The other housed 4 personnel, the scientific recording equipment, and also contained a shower which doubled as a darkroom. A Jamesway hut extending from the vestibule served as a dormitory.

The exact thickness of the ice at the site is unknown; but, from a preliminary analysis of the body-wave spectra (3), it appears to be approximately 2.7 km. The terrain is monotonously uneventful and devoid of animal or plant life, except for a few migrating birds. Drilling of the holes began as soon as the minimum requirements of the base-camp installation were satisfied. The instrument hole depths were predicated upon the depth required to reach an ice density of 0.83. This was found to occur at each in-

strument location at a depth of approximately 180 feet. All instruments are therefore approximately 180 feet below the surface. The holes were core drilled, which permitted excellent density/depth control. The upper 7-7/8-inch portions were cased with an 8-inch fiberglass pipe down to depths of 60 feet. The lower 4-7/8-inch portions of the holes were unsupported, and showed no visible evidence of closure during the first 6 months of operation. Drilling was accomplished by a portable, ski-mounted Acker Hillbilly powered by a Perkins diesel engine. Selected cores were depth-logged and encased in plastic bags for additional studies. Instrumentation, operation, and maintenance of the array were accomplished by personnel of the Geotech Division of Teledyne, Inc., from Garland, Texas.

On 17 August 1966, the Project Blue Ice Site was officially dedicated as the Inge Lehmann Station. The name was selected to honor Dr. Inge Lehmann, a noted Danish seismologist who was the head of seismology at the Danish Geodetic Institute until she retired. Since then she has continued her seismological research both in Denmark and in the United States. Dr. Lehmann presently resides in Copenhagen, Denmark.

SCIENTIFIC PROGRAMS

There were a total of four independent scientific-measurement programs under the project. The seismic program was accomplished under a joint activity arrangement between the Danish Geodetic Institute and the Air Force Office of Scientific Research (OAR). Dr. Erik Hjortenberg of the Danish Geodetic Institute, Copenhagen, Denmark, and Dr. Eduard Douze, the Geotech/AFOSR contractor, worked in processing and analyzing the seismic data.

The seismic instrumentation was a packaged "suitcase" system designed, assembled and field-tested by Geotech. The short-period downhole instruments were Geotech Model 20171A moving-coil seismometers designed to operate in shallow holes at

Figure 2. Inge Lehmann Station dedication ceremonies, 17 August 1966, attended by representatives of Denmark and the United States.

pressures up to 500 psi, and at tilt angles as great as 10 degrees. The instrument is capable of long-term operation at temperatures up to 120° F (49° C) and demonstrated satisfactory operation at bottom-hole temperatures encountered at Blue Ice of -33.2°F (-36.2°C). It has a natural frequency response adjustable from .75 to 1.05 Hertz. For Project Blue Ice the period was set at 1 second. A surface seismic station was installed 2,250 feet to the NNW (326°) of the base camp in a vault approximately 12 feet below the surface. It was instrumented with a Geotech Model 18300 short-period 3-component system. All cabling was accomplished using REA PE23, a 6-pair telephone cable suitable for direct burial. This is the same cable used in the Montana LASA (4). Available weather records of the area indicated no lightning protection would be required, and an uneventful summer validated the decision to eliminate the protectors. Recording was accomplished on a battery-operated Geotech 14-channel IRIG slow-speed analog tape recorder. This recorder has a capability for continuous operation for 33 days; however, the usual speed of 0.03 inches/second allowed only a 7-day operation due to the full use of all 14 channels. Two tapes were flown out on each biweekly resupply air mission. These were continuously processed during the summer by the Geotech Division in Dallas, Texas, permitting the data analyst to recommend different gain settings and adjustments via radio contact with the Blue Ice Site upon receipt of each tape. Each of the 4 vertical downhole seismometers were operated at dual gain levels.

The surface verticals were also operated at a dual level; but, because of channel limitation, the 2 horizontals were recorded at 1 gain level only. The remaining 2 tape channels were used to record station timing and WWV. This method of recording requires minimum power and magnetic tape; but it is limited to a dynamic range of 35 db (peak-to-peak) on each channel, a total peak signal range of 50 db (peak-to-peak) on each channel, and a total peak signal range of 50 db (peak-to-peak) using dual-level recording. The upper data frequency limit was 5 Hertz.

The magnetics measurement program was under the supervision of Dr. Johannes Wilhjelm of the Danish Meteorological Institute of Copenhagen. Dr. Wilhjelm maintained a magnetic observatory, located adjacent to the base camp, in which he recorded daily variations in the declination and in the horizontal and vertical intensity of the earth's magnetic field. These data were supplemented by data from several fixed observation sites in an array projecting east and west of the base camp.

A third program involved the measurement of the specific activity of the cosmic-ray-produced Si^{32}. One ton of ice below the 6-meter depth (from the pre-hydrogen bomb testing era of 1953) was collected and flown to Thule Air Base, Greenland, for analysis by scientists from the University of Copenhagen. The purpose of this investigation was to check whether or not the fallout of naturally produced Si^{32} is influenced by a continental effect. Comparison with a similar sample collected at Camp Century, 500 kilometers west of Inge Lehmann Station, should give the answer to this question, which is important for the possible use of Si^{32} for dating of icebergs (5).

In the fourth program, selected ice cores were preserved for crystallographic studies by personnel from the U.S. Army Cold Regions Research and Engineering Laboratories in Hanover, New Hampshire. In addition, daily synoptic weather observations were recorded every three hours, when possible, on precipitation, wind direction and velocity, barometric pressure, temperature, and cloud/sky conditions.

DATA ANALYSIS

Initial analysis of the data has been directed at determining the nature and character of the seismic background noise. It was obvious from the beginning that the noise level at this particular location was especially low. As each new hole was completed, it was immediately instrumented and instruments were adjusted for maximum gain. Gains were rapidly increased to as

Figure 3. Project Blue Ice personnel at Inge Lehmann Station. Major Young preparing to take off in snow toboggan which is normal means of surface transportation.

high as 1 million, but were leveled off at approximately 450 thousand. This was an order of magnitude higher than ever anticipated. With the completion of the entire array, it became obvious that Inge Lehmann Station was indeed in an unusual seismic environment. Previously, Station Nord on the northeast coast of Greenland was the most effective station; but now this new station is the most efficient station in Greenland for seismic-event detection. Much work remains to be done with the station data; but the very low noise qualities are already apparent.

FUTURE PLAN

Because of the uniquely low background noise associated with the Project Blue Ice data, it was decided to continue manned operations throughout the winter and on to the summer of 1967. Logistic operations began immediately to prepare the station for the four months of isolated winter operations. On 15 October 1966, four station contractor personnel were rotated into the Inge Lehmann Station to operate the array during the winter period. A rudimentary air strip with emergency lighting was hastily designed and installed to provide for any emergency evacuation.

A Christmas air drop of spare parts and Christmas parcels by C-130 Hercules was accomplished on Christmas eve at 1500 hours local time. This at least gave the Inge Lehmann Station personnel the sights

and sound of the outside world for a brief period.

Seismic-event reports are issued daily by radio to Thule Air Base from which they are relayed to the Danish Geodetic Institute, and by teletype to the U.S. Coast and Geodetic Survey at Rockville, Md., for inclusion in "Earthquake Data Report." The station abbreviation used by the Inge Lehmann Station is ILG. The on-site team was evacuated and replaced in late February 1967 by a new crew which will operate the station until September 1967.

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Dr. Erik Hjortenberg was educated at the University of Copenhagen, Denmark. He has worked in Greenland for several years, including the International Geophysical Year. During 1961-1963, he studied at the University of Alberta, investigating various properties of microseisms, their sources and the nature of microseismic waves. Since 1964 he has been employed by the Danish Geodetic Institute in the Department of Seismology, where his work has included continued research on microseisms. He has recently completed the preparation of a bibliography of microseisms, covering the years 1955-1964.

Major Durward D. Young, Jr., a geophysicist, joined the Geophysics Division, Directorate of Physical Sciences, AFOSR (OAR) in February 1965. He is responsible for a large portion of the basic research in seismology directed towards detection of underground explosions. He is an honor graduate from the University of Southwestern Louisiana, and earned an M.S. (Geophysics) from St. Louis University in 1965. He has held memberships in the Society of Exploration Geophysicists, Sigma Xi, Pi Mu Epsilon, American Association of Petroleum Geologists, and Phi Kappa Phi.

the effect of instruments on electrical noise

DR. DONN G. SHANKLAND
General Physics Research Laboratory, ARL

The measurement of the noise spectrum of an electrical device is a well-known analytic tool for investigating dynamical phenomena in the device. In a typical measurement on a semiconductor, one passes a constant current through the crystal (see Fig. 1), and observes a fluctuating voltage at the side arms A, B. This voltage is due to fluctuations in the carrier density in the region between the arms. When the fluctuating voltage is analyzed in a spectrum analyzer, the resulting curve can give important information concerning the generation, recombination, and transport phenomena taking place in the crystal. Typically, one may be able to resolve the spectrum into a sum of terms like $1/(1+\omega^2\tau^2)$, where the times τ correspond to lifetimes of various excited levels in the crystal. In addition, one may find a dominant asymptotic form for the spectrum varying as $\omega^{-3/2}$. This term should always be present when there is a diffusion mechanism operating in the crystal. (1) The task of the theoretician is to propose models of physical processes for the crystal which can account for the observed spectral form, and thus lead to increased understanding of the interactions and structure of the solid.

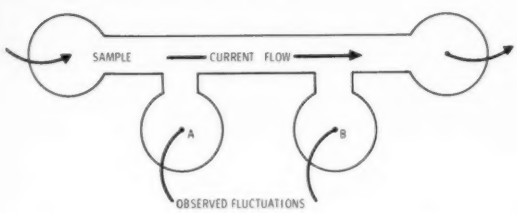


Figure 1. As a constant current passes through the crystal semiconductor, one observes a fluctuating voltage at the side arms A, B.

Dr. Donn G. Shankland, a research physicist with the General Physics Research Laboratory, ARL, has a B.S. in Physics (1950) from the University of Washington, Seattle, Washington, and an M.S. (1955) and Ph.D. (1961), both in Physics and both from the Ohio State University. He is currently doing work in many-body theory. From June 1950 to December 1958, Dr. Shankland served with the U.S. Air Force, reaching the grade of captain. He received the Air Medal (3olc), the Korean Service Medal, and the National Defense Service Ribbon. He is a member of the Institute of Electrical and Electronic Engineers, and the American Association of Physics Teachers, and has several publications to his credit.

Thus, it becomes of some importance when there is a disagreement between the available models and the form of the observed spectrum. This occurs, sometimes, when one knows from other experiments that a diffusion mechanism is involved in the carrier transport process, and yet one does not observe the "universal" $\omega^{-3/2}$ asymptotic behavior in the spectrum. An explanation for this discrepancy lay in postulating surface absorption effects, which removed the carriers as they diffused to the boundaries of the crystal. Such an explanation then involves new properties of the solid, and new

parameters associated with these surface effects.

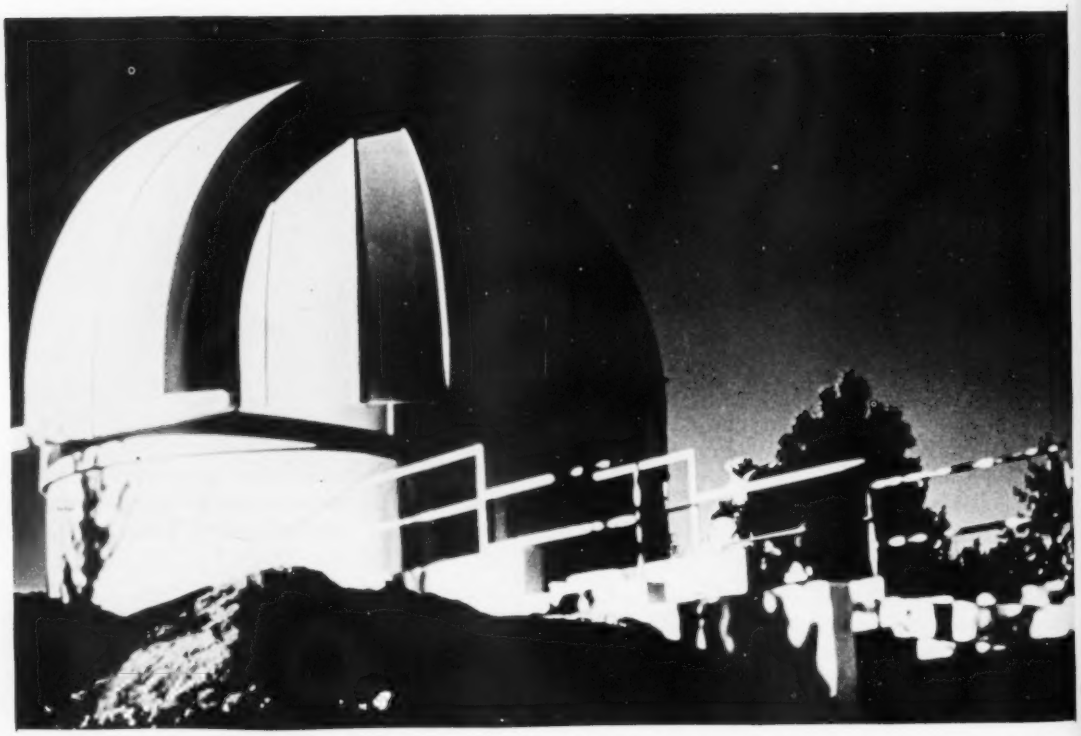
However, in a series of investigations into noise phenomena conducted at the General Physics Research Laboratory of ARL, it was observed that the $\omega^{-3/2}$ behavior depended critically on being able to observe fully the effect of an excess carrier located between the side arms of the sample, and to ignore it completely if it was outside the region of interest. As any physical instrument has an aperture which is not discontinuous, an investigation was made into the effect of the instrument aperture, i.e., the fringing fields near the side arms. Considerable messy mathematics led finally to the fact that the disappearance of the $\omega^{-3/2}$ dependence could be accounted for by fringing effects, and that the onset of $\omega^{-3/2}$ dependence could be correlated with the extent of fringing.

Thus, another model is available for explaining the absence of the expected asymptotic behavior of the frequency spectrum of the noise. The model postulates no new properties in the solid itself, but is an instrument effect likely to be found in every experiment at some point. It may, however, be masked by true surface absorption effects, so that the experimenter must then do additional tests to distinguish these effects.

REFERENCE

(1) van Vliet, K. M. and J. R. Fassett, "Electronic Transitions and Transport in Solids," Chapter 7 in Fluctuation Phenomena in Solids, R. E. Burgess, ed., New York: Academic Press, 1965.

AFCRL Monitors Solar Activity



The dome atop Sacramento Peak in Sunspot, New Mexico, houses the Observatory's flare–patrol equipment. This equipment includes a 6–cm telescope with coronagraph and photographic equipment attached. Instrumentation automatically monitors and records all solar activity.